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The Transition to Hydrogen as a Fuel

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Most of today's hydrogen is made from natural gas in large centralized plants because the predominant customers, refineries and chemical plants, need large amounts of hydrogen at these industrial locations. The hydrogen is either made where it is used or is put into large pipelines which can supply a number of plants. This is currently the least costly way to meet this demand.

If hydrogen is to be used as a transportation fuel, different production methods and delivery methods need to be considered to deliver it to a broad geographic area. No longer will very large amounts be needed at one location, but small amounts will be needed over a broad region. So the system will be much different than what we have today, but one thing will remain the same: the least costly methods will still fill the demand.

There is no single best production method for every region

There are several methods available today that can be considered for future hydrogen production and that may meet the three critical criteria for any future energy system — low cost, low GHG emissions and abundant domestic availability. Natural gas reforming, coal gasification, grid-based electrolysis, renewable-based electrolysis, biomass conversion and nuclear electrolysis are examples.

Each of the above technologies satisfies the three criteria in different ways and to different extents. Natural gas reforming has historically been inexpensive, emits some GHGs and comes mostly from domestic sources, but imports are rising which could affect future prices. Coal gasification is inexpensive for very large-scale production, yields twice the amount of GHGs to produce a given amount of hydrogen, and is made totally from domestic resources for the foreseeable future. Conventional grid electrolysis is very expensive, can produce as much GHGs on a life-cycle basis as coal gasification (depending on the source of electricity) to produce a given amount of hydrogen, and is all from domestic resources. Renewable electrolysis (photovoltaic and wind) is even more expensive, produces almost no GHGs, is from domestic resources, but is limited in supply in highly populated regions. Biomass conversion is expensive, produces almost no GHGs and comes totally from domestic resources, but a limited absolute amount is available in the United States. Hydrogen from nuclear electrolysis is more expensive than from coal or natural gas, produces almost no GHGs and is domestically available, but has disposal and security issues.

None of these technologies and feedstocks totally satisfies all of the criteria. The low-cost methods rely on imports or have high GHG emissions. The low-import and low-GHG options have high costs or limited availability. Some options clearly will work better in different parts of the United States, just as today different electricity generation methods work better than others in different regions. There is no one best production method that will work best everywhere. This flexibility, in terms of production method, is one of the strong advantages of using hydrogen as a fuel.

The future proportion of the hydrogen made from each of the methods depends on many factors, including the cost of hydrocarbons, the demand for hydrogen, how technological advances help to lower the costs of each technology, how society values low-GHG fuels, whether or not CO_2 can be safely and economically sequestered and what methods fit best with the regional supply and demand needs at any time. As these will change through time, so too will the choices for the future hydrogen generation and distribution infrastructure. We could see a mosaic of all of these different feedstocks used in different sizes in different situations. This will start to grow from the existing hydrogen, hydrocarbon and electricity infrastructure.

Demonstrations and pre-commercial phases

In this earliest phase, where we are today, hydrogen demand is very low with dispersed small fuel cell car demonstrations in a growing number of states transitioning into small pre-commercial fleet activity. Hydrogen availability is the primary fuel criterion. Initial hydrogen fuel demand will primarily be satisfied from existing hydrogen producers delivering hydrogen in small quantities by truck to relatively few, very small refueling stations. There are several industrial gas suppliers that can deliver from a number of terminals now with fairly broad geographic coverage. This is the most logical supply route to use because it minimizes investment until it is clear that hydrogen-fueled cars and trucks will be successful. This supply route however, has limited viability as it is very high-cost. Costs are as much as 5 to 10 times today's gasoline cost. As more hydrogen is needed to fuel an ever expanding demand over a broad geographic area, a different, lower-cost method will be needed to fuel a commercial growth period. Government support is needed for both demonstrations and for the research to develop the lower cost methods. The most promising ones appear to be small natural gas reformers and small electrolyzers.

Growing towards broad geographic availability

Once the technology moves out of the pre-commercial phase, costs become much more of an issue. Small distributed hydrogen production located at refueling stations will be the best method to meet customer demand in the medium term, starting 5 to 10 years from now. These refueling stations are likely to be located at a small fraction of today's gasoline stations and dispense both hydrogen and conventional fuels. The oil and gas industry has shown a real interest in helping to develop these technologies and in understanding how today's gasoline stations can evolve into hydrogen stations. The hydrogen will be produced at the station using either small natural gas reformers or small electrolyzers using off-peak grid power. Since either natural gas or electricity is available everywhere, this distributed production method should be practical for some time. These methods are attractive because (1) the hydrogen cost is much lower than from hydrogen delivered by truck, (2) the investment per station is not exceedingly large and (3) only a small fraction of today's stations (10 to 25%) need to be converted to begin the transition.

As it is not practical to capture and sequester GHGs from small distributed natural gas reformers and as most electricity is now made from fossil fuels, this will not start out as a low-GHG production route. Renewably produced electricity could be used where and when it is economically available in addition to off-peak electricity, resulting in lower GHG emissions. Together, renewably based electrolysis and natural gas reforming could form a near-term pathway to a lower-GHG future at reasonable cost.

Getting this process started involves overcoming the traditional chicken and egg problem. As there is no incentive for the current fuel suppliers to invest in a large number of stations that will sell very little hydrogen, some form of government action will be needed to provide incentives until volumes grow to the point of profitability. Although the hydrogen costs using these distributed methods should be much lower than from truck delivery, the fuel cost for a vehicle will likely still be higher than today's gasoline fuel costs.

Eventually small grids of these stations interconnected by pipelines may develop with some producing hydrogen and others just dispensing hydrogen. To further lower costs, these stations will eventually start to make both hydrogen and electricity (from a fuel cell) at the station. The electricity would power either an attached convenience store or perhaps a supermarket. These kinds of stations are ideal for refueling between 200 and 2000 cars per day.

Long-term, low-cost, large-scale production

Eventually, when a substantial hydrogen fuel market is established, the cost can be further lowered by making hydrogen in large centralized plants located near population centers - just as power plants generate electricity today. This hydrogen can then be shipped by pipeline to refueling stations that will store and dispense to the public. These large plants may use natural gas, coal, biomass or nuclear methods to make inexpensive hydrogen. In these plants, any CO_2 produced can be captured for possible sequestration. These plants work well when there are large concentrations of hydrogen cars in a region so that per-vehicle distribution costs are low; at least 150,000 cars in a local region seems to be the point at which this may occur. It is not possible to predict when these high densities will arrive, but it is very unlikely to happen for at least 25 years.

Some parts of the country will not have population densities large enough to support centralized production and in these parts distributed production methods will continue to be the most practical solutions. In either case the refueling stations already converted to handle hydrogen will continue to be the refueling locations. This will help to keep stranded costs of putting in the distributed infrastructure and then transitioning to a centralized system low.

It is likely that the lowest-cost hydrogen will be made at large centralized plants that co-produce both electricity and hydrogen and that direct the hydrogen to nearby population centers. For example, a future coal gasification plant running 80% coal and 20% biomass making both electricity and hydrogen with the CO_2 captured and sequestered could meet all of the energy system criteria. It can produce hydrogen competitive with today's petroleum costs, it will not release CO_2 to the atmosphere and it will be made entirely from domestic resources. This technology, however, is not perfected yet and needs more research before it is ready for use. This is also the case for some other large-scale technologies like nuclear methods.

The answers are not clear, especially in the long term

What the future hydrogen fuel system mosaic will eventually look like is not crystal clear. With all of the options available to make hydrogen, there is no one solution that best fits all cases. Different solutions are most practical in different regions and at different times through the transition.

Technology development, especially in carbon sequestration viability and in renewable electricity cost reduction can radically shift the future mosaic from what we might expect today.

Transition along this path is not risk-free and several areas need to be emphasized for the public and private sector to jointly pursue. Most important is technology research and development to answer the critical questions about the viability of fuel cell car technology and the ability to make inexpensive hydrogen as broadly and safely available as today's fuels. Neither question has yet to be answered to the extent that long-term decisions can be made. In addition to research is the need for more demonstrations of new technologies to gauge the current state of development and to gauge the public's willingness to change from our current infrastructure. Of the production technologies, small natural gas reformers and electrolyzer development should be emphasized as the most important solutions to the initial infrastructure.

It is apparent that hydrogen costs are going to be more expensive, at least initially, than our current fuels. Because of this, a transition to hydrogen as a fuel is unlikely to happen for purely business reasons. The initial markets will be too small and the risks of long term markets developing too high. Some form of market-based incentive is going to be needed to encourage hydrogen fuel use. And, if society places a higher value on making hydrogen in low GHG-emitting methods, which appear to be more expensive, then further market incentives will be needed to encourage using these methods.